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Technical Note N-1451

SANITARY LANDFILL SIMULATION - TEST PARAMETERS AND A SIMULATOR CONCEPTUAL DESIGN

By

William V. Miller, Carter J. Ward,
Richard A. Boettcher, and Norman P. Clarke

August 1976

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14 CEL-TN-1451	2. GOVT ACCESSION NO DN244027	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 SANITARY LANDFILL SIMULATION – TEST PARAMETERS AND A SIMULATOR CONCEPTUAL DESIGN		5. TYPE OF REPORT & PERIOD COVERED Final; July 1973–June 1975
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 William V. Miller, Carter J. Ward, Richard A. Boettcher [redacted] Norman P. Clarke		8. CONTRACT OR GRANT NUMBER(s) 16 YF57-572
9. PERFORMING ORGANIZATION NAME AND ADDRESS CIVIL ENGINEERING LABORATORY Naval Construction Battalion Center Port Hueneme, California 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62765N 17 YF57.572.001.01.002D
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command Alexandria, Virginia 22332		12. REPORT DATE 11 Aug[redacted]976
		13. NUMBER OF PAGES 42
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 46 p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

9 Final rept. Jul 73 – Jun 75

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Solid waste, simulation, landfill.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

391 111

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20. Continued

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SANITARY LANDFILL SIMULATION – TEST PARAMETERS AND A SIMULATOR CONCEPTUAL DESIGN (Final), by William V. Miller, Carter J. Ward, Richard A. Boettcher, and Norman P. Clarke
TN-1451 42 pp illus August 1976 Unclassified

1. Solid waste landfill 2. Sanitary landfill I. YF57.572.001.01.002D

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INTRODUCTION

Increased costs of solid waste handling and disposal at Navy shore facilities have resulted from new environmental requirements, higher labor and equipment costs, and increases in the quantity of solid waste being generated. These have necessitated setting a high priority on development of new methods and equipment that can reduce these expenditures.

To meet these requirements, the Naval Facilities Engineering Command (NAVFAC) tasked the Civil Engineering Laboratory (CEL) to review requirements; to develop systems, procedures, methods, and equipment for solid waste handling and disposal at Naval shore activities; and to perform exploratory development on simulation of sanitary landfills. The Navy is now almost totally dependent on landfilling for refuse disposal. The primary goal is to develop laboratory equipment capable of simulating a representative volume within a landfill to typify actual landfill conditions.

Background

Estimates based on a 1972 survey [1], now being updated by NAVFAC, show that the Navy uses 167 landfill sites to dispose of waste from 147 shore activities - in addition to sites used by service contractors to dispose of Navy waste. Most of these landfills comply only marginally with Navy mandatory guidelines [2]. In a FY-74 report on this project [3], CEL presented the results of a comprehensive Navy data/literature review and an examination of Navy landfilling objectives that revealed several common shore station problems with the landfill method for disposal of solid waste. These problems highlight an operational requirement that involves (1) increasing landfill capacity, (2) reducing pollution impact, (3) increasing site selection alternatives, and (4) ensuring successful field operations within the limited manpower and skill levels available to the Navy. A number of existing disposal sites are being closed [4] or are threatened with closure because of failure to meet pollution abatement requirements; difficulty is encountered in obtaining approval for new sites as short-lived existing sites become full.

Sanitary landfills are presently designed for burying solid waste in compliance with Environmental Protection Agency (EPA) operational guidelines. These guidelines pay great attention to consideration of public health, vehicle traffic, and aesthetics but not to optimum utilization of a site's overall solid waste disposal capacity. It is likely through advanced technology that disposal sites can be designed having a much larger capacity per unit of land area and still meet EPA guidelines.

However, information on the physical/structural properties of refuse/earth composites sufficient for advanced design is not available, nor is it being obtained. A lysimeter, a container in which a quantity of solid waste is allowed to decompose as in nature, has frequently been used to yield information on the composition and generation rate of landfill gases and leachate [5,6]. However, what is needed is information to predict the effectiveness of landfill designs and operational procedures for accurately comparing the benefits and costs of alternatives.

Field studies have been conducted to determine surface settlement rates and magnitudes. Results of two studies conducted at landfills in Santa Clara and Los Angeles Counties of California are reported in an EPA summary [7] of landfilling practices and applications. These studies compared the decomposition obtained in aerobic landfills with decomposition and appearance of material obtained in the normally anaerobic landfill. Examination of core samples taken at the end of a 4-year study period showed that waste in the aerated cell (aerobic decomposition) had undergone measurable decomposition, except for plastics and other inert materials. In anaerobic cells organic waste components were not decomposed and were easily identified. Another major EPA study [8] of factors affecting use of completed landfill sites indicated that up to 100 years may be required for decomposition and for related settlement to cease.

In addition, a number of full-scale field demonstrations have been or are being made of innovative landfill techniques. These include baling or shredding prior to landfilling, aeration to prevent the formation of methane gas, use of liners to collect leachate rather than attempting to prevent its formation, and special compaction techniques such as surcharging. The demonstration results, in general, have been inconclusive in predicting future designs because significant parameters were uncontrolled.

Responding to these technology gaps, Reference 3 outlined concepts for a laboratory testing unit - a sanitary landfill simulator (SLS) - to obtain the needed information. The proposed equipment could simulate at reduced scale an actual landfill section, accelerate its decomposition, and measure physical characteristics related to its mechanical/structural properties as they change with decomposition and settlement.

Laboratory experiments are preferable to demonstrations or full-scale field tests because results are obtainable at lower cost. They are subject to close control and can be less expensively repeated to obtain statistically valid results - provided acceleration of the natural decomposition process is feasible.

For rapid decomposition of organic waste products several methods - such as high and low temperature oxidation, chemical oxidation, high and low temperature pyrolysis, enzyme liquefaction and steam ''cooking'' - can effect volume reduction much more rapidly than the normal bacteriological decomposition process. By laboratory use of these methods under controlled conditions, it may be possible to accelerate landfill decomposition by a factor of 100:1 or more.

Summary

Specific physical characteristics of the simulated landfill were selected for test monitoring, based on their correlation with potential landfill-design/operating-procedural changes. The need to monitor these characteristics, along with the need to simulate sections of a landfill under varying conditions, provided the basis for the design requirements of the sanitary landfill simulator (SLS). These requirements were outlined relating to (1) simulator scaling, (2) landfill depth simulation, (3) simulation of landfill thermal and oxygen environments, (4) operation and maintenance, and (5) instrumentation and control.

A conceptual design was developed for an SLS capable of simulating a section within a landfill that would represent actual landfill conditions. A method of loading, or surcharging, solid waste in a test chamber to simulate landfill depths between 0 and 200 feet was developed. An instrumentation and control system was schematized for monitoring settlement/decomposition, flow and generation rates for gas and liquid, and chamber pressure and temperature. A method of obtaining horizontal core samples from within the chamber that would be suitable for permeability testing was conceived and verified through experiments in core sampling.

The basic concept was developed for a nominal test chamber temperature not to exceed 200°F. However, in the interest of pursuing accelerated decomposition methods, the possibility of high temperature (e.g., 1,500°F) operation of the chamber to support pyrolysis was considered. A brief discussion of the impact of such a requirement on test equipment is presented herein, in which potential design solutions are offered for the various component and instrumentation problems anticipated in a high temperature environment.

DISCUSSION

In early FY-75 an examination of the possibility of conducting controlled landfill experiments to evaluate environmental and other effects under laboratory conditions was completed. This study revealed two areas of uncertainty in the experimental approach. First, the need for simulating many locations made the selection of design and operational procedures (independent parameters) and the selection of physical characteristics to be observed (test parameters) difficult. The number of test combinations for obtaining statistically valid, quantitative results were found to be very large, as shown in Table 1.* Second, the literature contained little information that permitted a rational approach to acceleration of refuse decomposition that would be representative of actual physical characteristics. Both technical uncertainties had to be resolved before costs and benefits of laboratory experiments could be estimated. With NAVFAC

* There are as many as 45 independent conditions related to the way a landfill is designed and operated; there are 16 independent conditions related to climate, soil type, and age of fill.

Table 1. Summary of Experimental Conditions for Testing in Sanitary Landfill Simulator

I. Conditions Related to Field Operations Being Simulated

A. Preprocessing

1. None – raw refuse
2. Shredded
3. Baled
   (a) Low density
   (b) High density
4. Densified (65 lb/ft^2, minimum)

B. Initial Placement Procedure

1. Amount of cover soil
   (a) Normal
   (b) Excess
   (c) Substandard
2. Equipment Operation to Achieve Specified In-Place Density
   (a) 800 lb/yd^3
   (b) 1,000 lb/yd^3
   (c) 1,200 lb/yd^3
3. Moisture Content Control for Curing Filling
   (a) Dry – as received
   (b) 40%
   (c) 60%
   (d) Field capacity
4. Additives During Filling
   (a) None
   (b) Lime (pH control)
   (c) Nutrients (n, p, k) and Trace Elements
   (d) Biological Seed Material
      (1) Sewage Sludge
      (2) Mutant Cultures
5. Special Placement Procedures to Improve Stability
   (a) None
   (b) ''Arching''
   (c) Surcharging of Intermediate Cover

C. Completion Procedures, Special Operations Maintenance

1. Normal completion – 2-foot cover, grading and planting
2. Use of impervious membrane in connection with normal completion or other means of sealing, to prevent rainwater entry or gas escape
3. Leachate Collection/Recirculation
   (a) Leachate Removed for Disposal
   (b) Leachate Recirculated
      (1) Without Treatment
      (2) With Treatment
         (a) Control pH
         (b) Add Nutrients
         (c) Remove Toxicity

continued

Table 1. Continued

4. Collection of Gas for Control/Utilization
5. Regrading for Control of Runoff (after settlement)

   (a) With earth
   (b) With refuse

6. Surcharging
7. In-situ Composting

D. Ultimate Use of Completed Site

1. ''Natural'' Open Space
2. Landscaped Open Space

   (a) No irrigation
   (b) Buried sprinkler pipes

3. Parking

   (a) Unpaved
   (b) Paved

4. Buildings with Lightly Loaded Foundations

   (a) Spread Footings
   (b) Piles

      (1) Wood, Concrete or Steel
      (2) Sand

   (c) ''Sato Wedge,'' or other Special Designs

II. Conditions Related to Landfill Situation

A. Refuse Composition – ''Base Facilities Waste'' as characterized by CR 73.011 will be used, as most stations operating their own landfills collect and dispose of base wastes only; residential wastes most often handled by contract.

B. Refuse Particle Size (as required for similitude)

C. Type of Cover Soil

1. Sandy Loam
2. Clay Loam
3. Silty Sand

D. Age Simulated

1. Completed Fill
2. 10 years
3. 20 years
4. 50 years
5. 100 years

E. Method of Age Simulation Representative of:

1. Cool/Wet Climate (Cincinnati, Ohio)
2. Warm/Wet Climate (Orlando, Florida)
3. Warm/Dry Climate (Los Angeles, California)

F. Rainfall on Completed Landfill (water balance; i.e., net infiltration)

1. Evapotranspiration in Excess of Rainfall (Los Angeles - ET 840mm, P 378mm)
2. Evapotranspiration Equal to Rainfall (Orlando – ET 1,206mm, P 1,342mm)
3. Evapotranspiration Less Than Rainfall (Cincinnati – ET 766mm, P 1,025mm)

and benefits of laboratory experiments could be estimated. With NAVFAC concurrence [9], it was decided to establish, with some assurance, the potential for SLS equipment design before proceeding further with the design of experiments.

Selection of Test Parameters

Priorities for simulation experiments were evaluated to establish which parameters should be monitored during testing; i.e., those parameters that affect potential changes in landfill design and operating procedures.

The development of technical requirements for a laboratory program of sanitary landfill simulation and test began with consideration of possible beneficial changes in landfill design practices and field operating procedures. Benefits, of course, had to be measurable in terms of specific landfill physical characteristics to evaluate and compare the changes on some rational basis.

The physical characteristics for test monitoring were determined from the numerical ranking of 17 selected landfill-design/operating-procedure changes. The ranking of these changes was in terms of three factors: first, the cost and complexity of the required procedure; second, the pollution abatement benefits potentially achievable; and third, the contribution to long-term stability of the landfill. This ranking process is illustrated in Table 2. Each of the potential changes was rated subjectively, from 1 to 17, for each of the three factors, number 1 indicating least cost or greatest benefit and number 17 indicating the opposite. The ''Total'' column provides the basis for priority ranking of the potential changes; i.e., the lower the sum in the ''Total'' column, the higher the priority. Highest priority is indicated by numeral 1. These priorities refer to which potential changes are to be included in the test procedure; the high four are:

1. Compaction of shredded refuse to an initial, in-place density of 1,500-lb/yd^3

2. Compaction of raw refuse to an initial, in-place density of 1,200-lb/yd^3

3. Compaction of shredded refuse to an initial, in-place density of 1,000 lb/yd^3

4. Densification processing prior to landfilling

Six additional changes were assigned fifth priority, and seven were excluded because of poor pollution control ranking.

Upon completion of the priority ranking of design/operational procedure changes from one to five, Table 3 was drawn. The purpose of Table 3 was to provide a basis for selection of those physical characteristics to be monitored during simulation and testing. Each characteristic was considered as to whether or not each of the procedures listed would change it significantly from its state or value corresponding to a

Table 2. Priority Ranking of Design/Procedural Changes for SLS Experimental Design

Procedure	Basis for Change	Ranking Value				Priority
		Cost/ Complexity	Pollution Control	Stability	Total	
Density Considerations						
Raw Refuse	Initial density, lb/yd^3					
	600[a]	Present Practice	Present Practice	Present Practice		
	800	2	13	10	25	*[b]
	1,200	4	8	5	17	2
Densification		17	1	1	19	4
Balefilling	Density, lb/ft^3					
	30	15	12	9	36	*
	50	16	9	3	28	5
Surcharging		10	10	7	27	5
Shredding	Initial density, lb/yd^3					
	500	6	14	11	31	*
	1,000	7	7	4	18	3
	1,500	8	5	2	15	1
Biostabilization Considerations						
Rainwater entry	Prevention with membrane or other means	12	4	12	28	5
Precomposting/ in-situ composting		13	6	8	27	5
Gas Production	Control or use	9	2	15	26	5
Moisture content	Control during filling	1	15	13	29	*
pH control Additives	Lime or $CaCO_3$ N, PO_4, K	3	15	13	31	*
Bacteria seeding	Cultures or sewage sludge	5	15	13	33	*
Leachate	Collection or recirculation	11	3	14	28	5
Placement	Special procedures, such as "arching"	14	11	6	31	*
Foundations	Special designs, such as sand piles or "Sato" wedge	Dependent on building construction				

[a] Used as a control.

[b] Items marked with * were excluded from Priority 5 because of low pollution control ranking.

''control'' ocedure. The control procedure was designated as the first list , i.e., raw refuse compacted to an initial density of 600 lb/yd^3. Each physical characteristic judged to be significantly sensitive to a particular procedure change when compared to the control procedure is designated by a dot opposite that procedural change. Those characteristics having four or more dots were selected as primary characteristics for monitoring during tests inasmuch as they represent the greatest correlation between changes and benefits.

As an example, the performance of a landfill containing refuse densified to 65 lb/ft^3 prior to placement might be expected to show a significant difference from the control - i.e., lightly compacted (600 lb/yd^3 initial density) raw refuse - in those settlement/consolidation characteristics related to both loading and decomposition as well as gas permeability, foundation characteristics, and field capacity. The benefits associated with changes in liquid permeability appeared to be somewhat indeterminate for comparing a densified landfill with the control, while TDS* Reduction of Leachate and In-Situ Density vs Depth were considered not suitable for comparison. By considering and judging each of the selected procedures in this way, the most significant physical characteristics for evaluating procedure changes were identified as follows as primary characteristics:

1. Settlement/consolidation from loading - rate, total, differential, and rebound

2. Settlement/consolidation from decomposition - total and differential

3. Gas permeability - in the horizontal and vertical directions, dry and saturated

4. Liquid permeability - horizontal and vertical

5. In-situ density vs depth

6. Field capacity

As a result of the foregoing determination of high priority procedure changes and primary physical characteristics, the complexity of the SLS equipment and testing is held to a minimum.

Technical Requirements

Table 4 summarizes the technical requirements for design of the SLS, which are discussed below:

1. Size and Shape. Loading considerations, similitude, and logistics are the principal determinants of SLS size and shape. The cylindrical shape specified is the most efficient for withstanding internal pressure. It was determined that (a) the chamber be capable of accepting solid waste items with a maximum dimension of 6 inches, (b) the diameter be large enough to minimize wall effects, and (c) its height be sufficient to preclude bridging.

* Total dissolved solids.

Table 3. Landfill Physical Characteristics Obtainable by Simulator Experiments

DESIGN/OPERATIONAL PROCEDURE VARIABLES	Settlement/Consolidation From Loading	Rate	Total	Differential	Rebound	Settlement/Consolidation From Decomposition	Total	Differential	Gas Permeability	Horizontal	Vertical	Liquid Permeability	Horizontal	Vertical	*TDS Reduction of Leachate by Natural Soil Ion Exchange	In-Situ Density vs Depth	Foundation Characteristics	Plate Bearing	Shear	Gas Production	Composition	Quantity/Rate	Leachate Production	Composition	Quantity/Rate	Leachate Toxicity to Biomass	Duration of Initial Aerobic Decomposition Phase	Decomposition ''Half-Life''	Field Capacity
DENSITY CONSIDERATIONS																													
Raw Refuse (initial density), lb/yd^3																													
(a) 600		•	•	•	•		•	•		•	•		•	•	•	•					•	•				•			•
(b) 800																													
(c) 1200		•	•	•	•		•	•		•	•		•	•		•													•
Densification		•	•	•			•	•		•	•							•	•										•
Balefilling (density), lb/ft^3																													
(a) 30																													
(b) 50		•	•	•			•	•		•	•		•	•				•	•										•
Surcharging		•	•	•			•	•		•	•		•	•		•													•
Shredding (initial density), lb/yd^3																													
(a) 500																													
(b) 1000		•	•	•			•	•		•	•		•	•		•													•
(c) 1500										•	•		•	•															•
BIOSTABILIZATION CONSIDERATIONS																													
Prevention of rainwater entry with membrane or other means		•	•	•	•		•	•																					•
Precomposting/in-situ composting															•						•	•		•	•	•			•
Gas production for control/use																													
Moisture content control during filling																													
pH control (lime or $CaCO_3$) and additives (N, PO_4, K)																													
Bacteria seeding (cultures or sewage sludge)																													
Leachate collection/recirculation													•	•	•											•			•
Special placement procedures, such as ''arching''																													
Special foundation designs, such as sand piles or ''Sato'' wedge																													

*TDS = Total dissolved solids

Table 4. Synopsis of Design Criteria for Sanitary Landfill Simulator

Item	Condition	Requirements
Size and shape	Scaling factors for cylindrical shape	a. Maximum dimension, 6 in. b. Minimum wall effects c. To preclude bridging d. Volume, 2 tons maximum
Compression	Maximum layer thickness	a. 1 ft at 1,200 lb/yd^3
Load	Loading device/pressure platen	a. Even distribution b. Maintenance
Bulk density measurements	Initial fill	--
	Settlement	a. During waste decomposition b. During high load tests
	Location of instruments	a. At surface b. Two intermediate points c. On removal of load
Insulation and temperature control	Control	a. To represent field conditions b. To accelerate decomposition
	Ambient	a. 30^{o} to $100^{o}F$
Gases	Anaerobic environment (simulation)	a. To purge oxygen b. For sealing
	Aerobic condition (simulation)	a. Controlled air flow
	Gas generation	a. Controlled one-way valve to remove gas to simulate atmospheric pressure changes b. Instrument to measure flow rate c. Valve system for monitoring gas composition
Liquids	Distribution system	a. To spread liquids at surface
	Collection system Connections Connections	a. At the bottom for analysis a. For flooding and draining when system full of refuse
Simulated Decomposition	Method evaluation	a. High temperature oxidation b. Pyrolysis c. Steam d. Chemicals
	Effective level for each method	a. Pressure b. Temperature c. Quantity d. Rate e. Duration
	Landfilled material	a. Structurally similar to naturally decomposed solid waste after 5, 10, 25, 50, and 100 years
	Applicability	a. Determined for each method
Operation and Maintenance	Vibration and noise	a. Control
	Corrosion resistant material	a. Internal environment b. External environment
	Automation	a. Minimize manpower in operation
	Odor	a. Control system

The effects of the relative size of individual solid waste particles, cover dirt particles, cell dimensions, cover dirt thickness, and the inside dimensions of the SLS must be considered to assure valid results [10]. The problems of similitude for hydraulic model studies have been thoroughly investigated [11]; through the use of models a hundred-fold reduction in size from natural scale is often possible.

A maximum chamber volume equivalent to 2 tons of refuse is specified as being within laboratory capability for supplying, processing, and eventually disposing of material being tested.

2. Compression and Loading. Simulating a section within a landfill for testing may involve as many as three phases during which compression is required: first, to produce the density achieved initially by landfill equipment; second, to simulate the conditions under which decomposition takes place; and third, to simulate the condition of test. The first two phases have to do with preparation of the test sample, while the third phase is part of the test itself. Phases two and three simulate canyon landfills or multilift area fills where refuse may be buried to depths as great as 200 feet.

The first compression phase requires the provision of a mechanism capable of compressing a mixture of soil and refuse as it is placed in the SLS in layers of 1-foot maximum thickness, simulating a typical landfill lift. Initial in-place densities up to 1,200 lb/yd^3 are often obtained in municipal landfills. It is a density which, if it could be achieved regularly in Navy practice, would double the life of most Navy landfills.

Compression phases two and three require a means of applying an evenly distributed load. Since decomposition of waste in the simulator would be carried out under load, the loading device must be capable of maintaining a set load independent of refuse volume changes. The same device must provide a heavy load to simulate conditions of deep burial for tests to measure the pressure-related characteristics of permeability [8]. To apply the necessary pressure over a surface 3 to 5 feet in diameter, a very large force is required. For instance, 200 feet of overburden material compacted to 1,200 lb/yd^3 would produce a pressure of 8,900 lb/ft^2 and exert a force of 87 tons on a 5-foot diameter area. Dead weight such as sand bags or metal bars were considered impractical both structurally and because of the prohibitively large manpower requirement for routine handling.

3. Density and Settlement Measurements. Bulk density measurements are essential to monitor consolidation that takes place over time. For this purpose, the measurement of settlement is considered adequate. Differential settlement (areal variations) and vertical variations in settlement are important. Such measurements must account for rebound that occurs with surcharge removal. All are considered significant as characteristics that influence the performance of actual landfills.

4. Insulation and Temperature Control. One method of accelerated decomposition that might be employed is biological. To achieve high biological decomposition rates requires optimization of environmental conditions, one of the most important of these being temperature. Accordingly, the SLS controls must respond to temperature changes resulting from the ambient heat as well as heat generated internally by biological activity. Insulation, heating and cooling equipment, and sensors for monitoring temperatures and controlling heat flux are therefore specified.

5. Gases and Liquids. Biological activity in landfilled waste is influenced strongly by gases and liquids that permeate the voids of the material being decomposed [12]. During simulation gas may be externally supplied by purging or may enter naturally either by the ''breathing'' that occurs with temperature changes in the simulator or by the pumping action of atmospheric pressure variations. In field situations, liquid is normally supplied by rainfall but can also result from saturation by ground water or from capillary action. Both gases and liquids (leachate) are also produced by the decomposition process itself. In the simulator, it is specified that provisions be made for monitoring both aerobic and anaerobic modes of decomposition, and for monitoring both generation rates and composition of gases evolved. Equipment and connections are required to permit both ''open chamber'' and ''closed chamber'' operations for maximum flexibility. Simulation of the liquid environment requires a distribution system for spreading water or leachate on the surface of the waste. Provisions for collecting leachate from the bottom of the simulator and for flooding and draining the chamber are needed for test operations.

6. Simulated Decomposition. Opinions provided by professional engineers knowledgeable in landfill operations, design, and research [13,14] indicate that simulating decomposition is a key factor in the feasibility of SLS experiments. High rate decomposition methods would be required to produce a material for test in a reasonable time frame. The material under test must respond in a manner structurally similar to solid waste that has undergone decomposition for 5, 10, 25, 50 or 100 years.

By providing optimum growth conditions and mutant strains of bacteria [15], a several-fold rate increase in biological decomposition is possible for simulation of initial landfill life. Where 10 to 50 years are to be simulated, different methods are required; e.g., high temperature oxidation, pyrolysis, or the use of steam or chemical additives.

In the event that further work is undertaken on the landfill simulator, the problem of simulating accelerated decomposition should be addressed and resolved prior to conducting any further effort on simulator equipment design and fabrication. It is important to note that this remains the only problem which the question of technical feasibility cannot yet be answered.

7. Operation and Maintenance. The primary operation and maintenance considerations for the SLS design were: (a) material handling with minimization of manpower, odor, vibration, and noise; (b) shielding of the material being tested from the effects of internal equipment corrosion; and (c) protection of the equipment from external corrosion if installed outdoors. These are based on the expectation that simulator experiments would be conducted in-house at CEL.

CONCEPTUAL DESIGN

This report includes the conceptual design and analysis of a sanitary landfill simulator (SLS) but not detailed engineering drawings.

Shape and Size Analysis

The SLS is basically a laboratory tool which can be used to simulate a landfill environment and, because of logistics and cost, should be made as small as practical. The assumption is made that the refuse material and cover soil will be placed inside the simulator chamber in alternate layers, where the height of the refuse layer is a minimum of three times the height of the cover soil layer (as in actual practice). It is believed that particle size and layer thickness directly affect the minimum size of central zone (measurement zone) over which representative settlement measurements can be obtained. Further, the method of load application and the confining and frictional characteristics of the container determine the minimum container dimensions permissible for simulating adequately the loading and confinement representative of field conditions.

Chamber Height Analysis

For rigid radial confinement and a rigid loading platen such as a piston in a cylinder, cushioning zones should be provided that are at least as large as measurement zone height. The CEL soil tank discussed below has a maximum chamber height in excess of 6 feet which will provide a measurement zone of 2 feet. This measurement zone height should be adequate to simulate at least one full layer (i.e., one refuse layer with cover soil). The minimum refuse layer height should not be less than twice the maximum particle size (e.g., 1 foot for a 6-inch item). For bladder or bag loading used in a vessel such as the soil tank, where pressure is evenly distributed over the surface, a larger measurement zone height can be expected to provide good settlement measurement.

Chamber Diameter Analysis

Extensive radial cushioning is required to preclude arching of the refuse and cover soil layers due to a high-friction tank wall. Published guidelines are indefinite on this point and the unknown frictional characteristics of the refuse make predictions even less certain. For a bladder-loaded tank, a tank diameter D_T of at least the sum of the measurement zone diameter D_m plus the product of the measurement zone height H_m times tan $(45^o + \phi/2)$ would be required.*

Hence,

$$D_T > D_m + 2H_m \tan (45^o + \phi/2)$$

where ϕ is the average friction angle of the refuse and cover soil at the radial tank wall. For the soil tank, D_T is 60 inches and the minimum acceptable measurement zone dimensions are H_m = 16 inches and D_m = 12 inches, as shown in Figure 1. This minimum measurement zone is determined on the basis that its diameter equals at least twice the maximum refuse particle dimension, and that it contain one layer each of cover soil and refuse. The tangent of the friction angle (coefficient of friction) needed to satisfy the above equation for the minimum measurement zone is 0.365, i.e.,

$$\phi \leq 2 \left(\tan^{-1} \frac{D_T - D_m}{2H_m} - 45^o \right)$$

$$\phi \leq 2 \left(\tan^{-1} \frac{60 - 12}{2 \times 16} - 45^o \right)$$

so, $\phi \leq 22.6$ degrees

or $\mu_{average} \leq 0.416$

and from Figure 1, $\mu_{average} = (\mu_{cover\ soil} + 3\mu_{refuse})/4$

Therefore, based on $\mu_{cover\ soil} = 0.58$,

$$\mu_{refuse} \leq 0.361$$

Figure 2 shows the test method used to determine the coefficient of friction for a sample of solid waste. It is important to note that for good settlement measurements, the coefficient of friction for the refuse should not exceed 0.361. It is suggested that to ensure good results, the chamber sidewalls be coated with cooking grease. Laboratory tests at CEL using Crisco shortening between the refuse and rough-surfaced steel, have resulted in an average coefficient of friction of 0.33 (see Figure 3).

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* CEL memo L42/DTG/ilm of 6 Mar 1975.

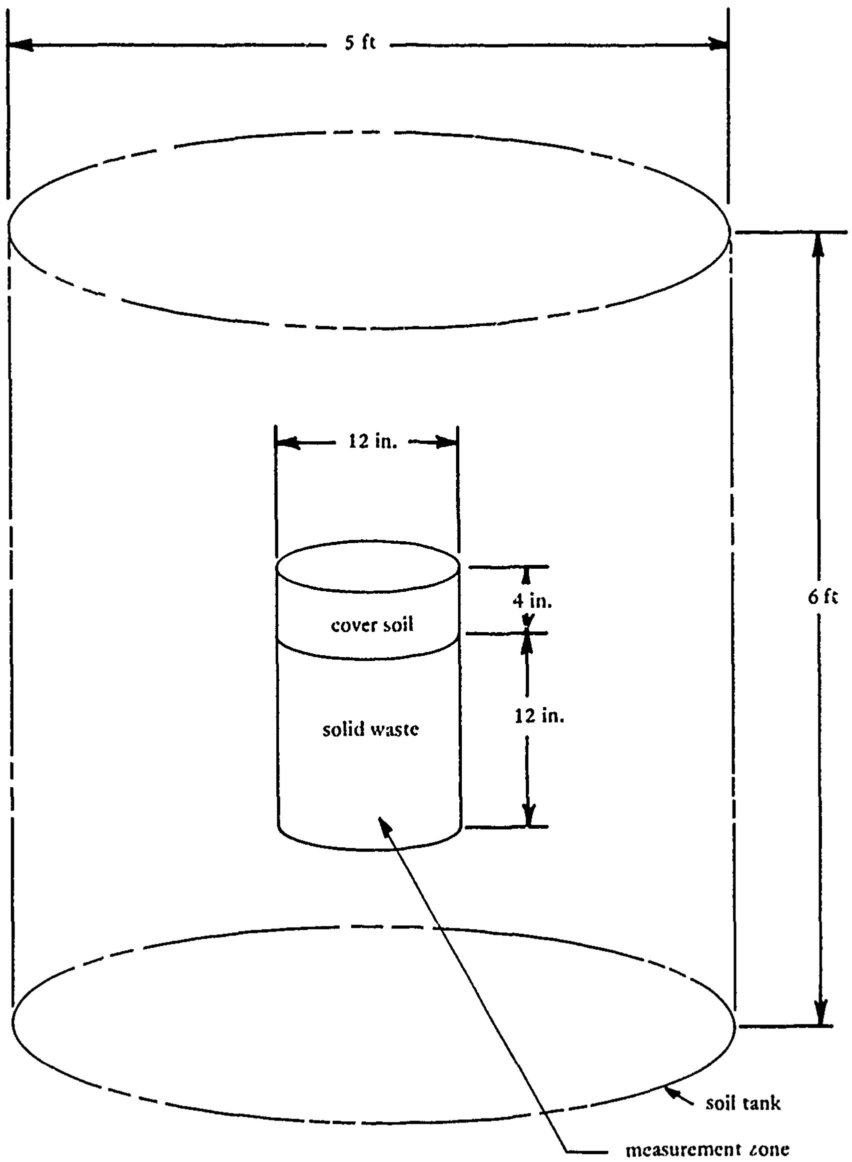


Figure 1. Measurement zone.

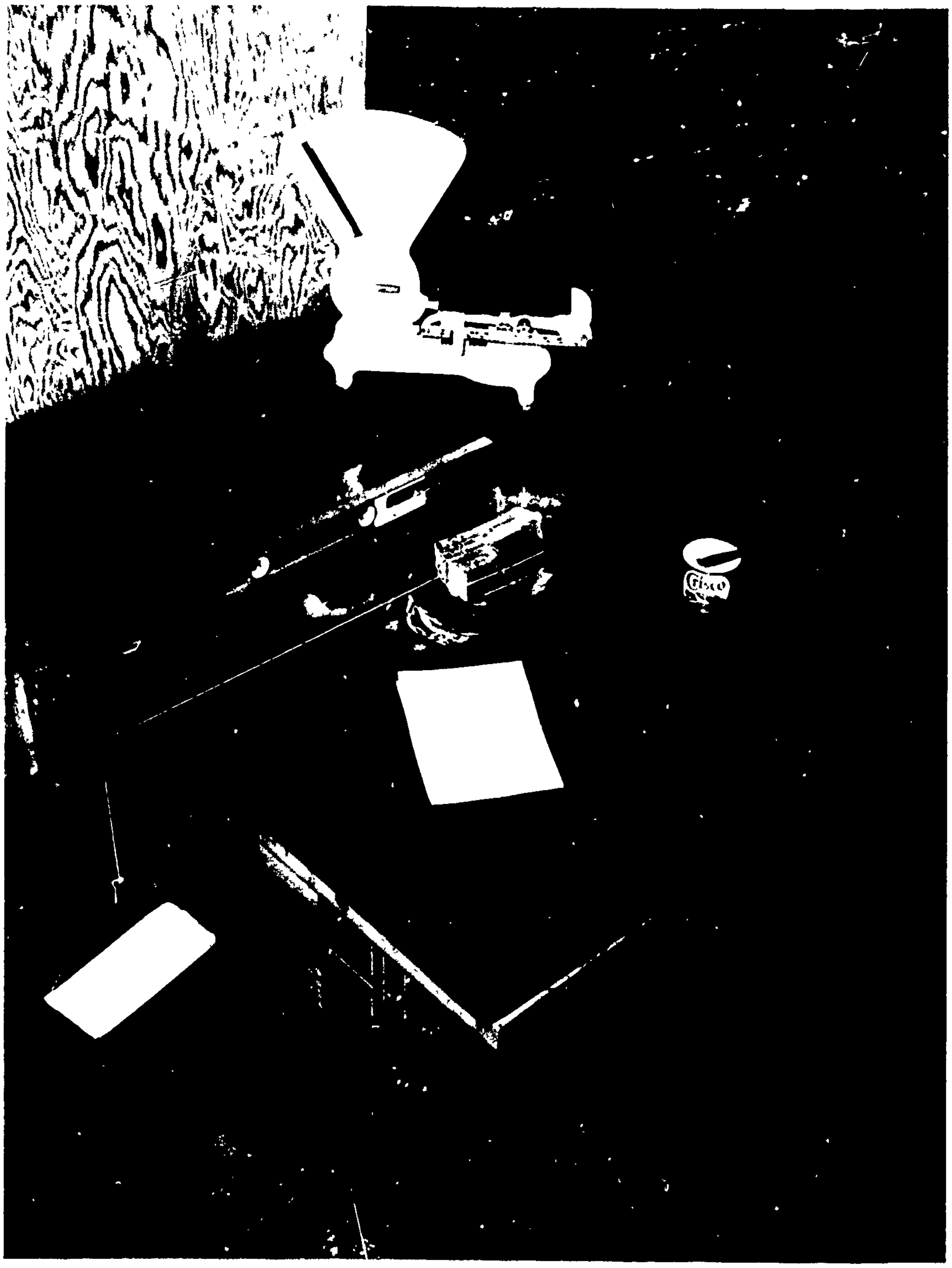


Figure 2. Experimental test setup to determine coefficient of friction between densified paper refuse and steel with shortening for lubrication.

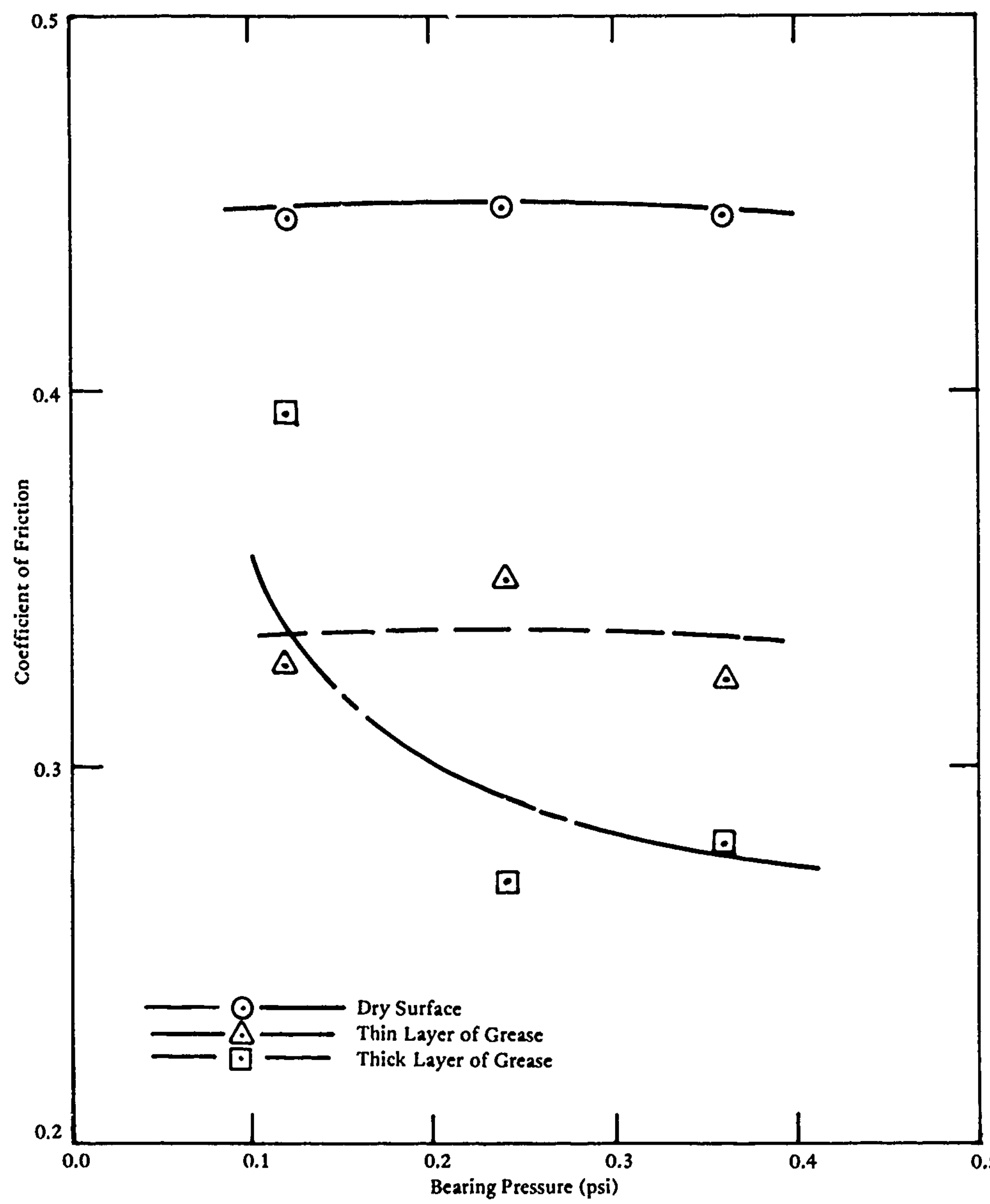


Figure 3. Coefficient of friction test results for densified paper and steel.

The tests were conducted in an air temperature of 67°F, and the grease was fairly hard; at higher temperatures the coefficient of friction should be considerably less. The refuse material used in the experiment was highly densified paper products from the CEL refuse densification project. This material is expected to have a higher coefficient of friction than general refuse. The steel surface was a plate with a rusty surface of about 152 to 250-microinch rms average finish. It is recommended that the tank rings be sand-blasted or smoothed and painted with a smooth enamel, and a similarly finished surface be tested. This refinishing should preclude arching effects detrimental to good settlement measurements.

Scaling Factor Analysis

In soils research, it has been found that the behavior of granular materials may be determined accurately by testing samples of scaled materials, fabricated by reducing the sizes of the larger particles by factors of two to four. This approach is recommended for the subject tests as a means of reducing testing cost, for increasing the possible number of tests, and for permitting greater flexibility in adjusting test conditions.

Test Chamber (Soil Tank)

The selected test chamber, called a soil tank, is shown assembled in Figure 4. It consists of a series of steel rings 5 feet in diameter, 3/8 inch in radial thickness, and 5 inches in height, stacked with a single vertical axis. The top layer of material in the tank is vertically loaded during test by pressurization of an enclosed inflatable bag at the surface, which works much like an accordion. The bag is capable of simulating pressures equivalent to 200 feet of refuse and has a 3-foot stroke. The radial containment minimizes bag damage from sidewall friction. Advantages of this design are: (1) easy variation of the tank depth and (2) installation or removal of the rings as desired for convenience while setting up or tearing down a test specimen. The soil tank's volume and shape meet SLS requirements, and its operational practicability has been demonstrated. Simple and efficient methods of filling and emptying refuse from the chamber are possible because the steel rings can be installed and removed manually. To alter the CEL soil tank's functions to satisfy SLS requirements, detailed engineering drawings and specifications are needed to:

1. Modify rings to accommodate a refuse specimen corer and SLS instrumentation connectors

2. Sand and paint the ring's internal walls with a smooth enamel that has low skin friction and is resistant to the anticipated corrosive agents

3. Refurbish all parts and components to accommodate SLS sealing and environmental requirements

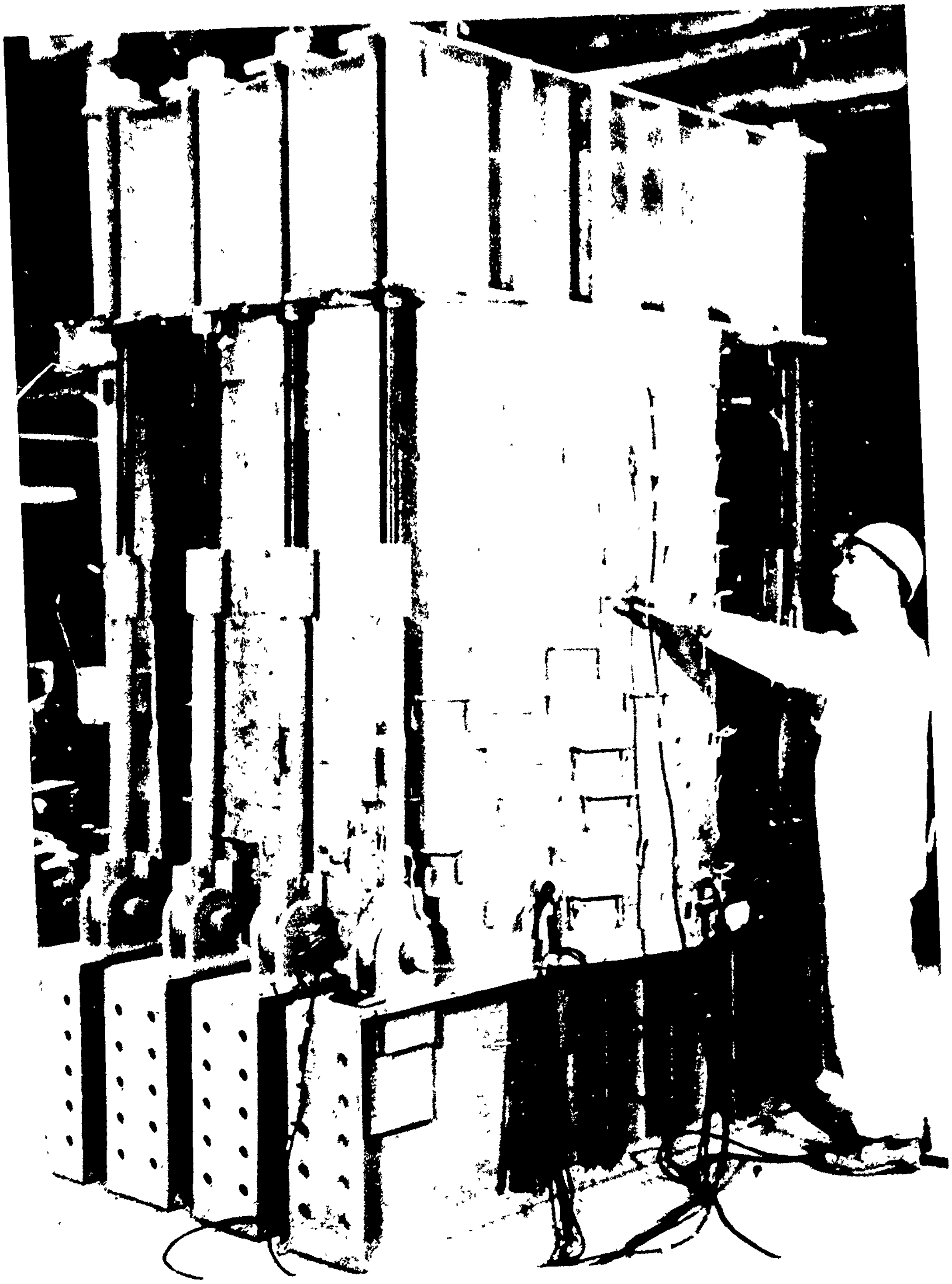


Figure 4. Soil tank.

4. Incorporate load cells on the tie rods to provide for the proper preloading

5. Modify ring seats to accommodate asbestos seals if high temperature operation is required

Specific component materials for interior plumbing, connectors, etc., have not all been selected; however, all components and equipment included in the conceptual designs can utilize materials resistant to corrosion by solid waste and by its products of decomposition.

In regard to exposed material and equipment, the SLS should be housed to simulate the thermal environment of a typical landfill. This shelter should be large enough to provide protection from the outdoor environment for all equipment and instrumentation. The shelter should also have a door large enough for a forklift, and should be able to house a gantry. The facilities, in addition to the soil tank composed of lightweight rings which can be manually installed and removed, should provide an environment for high productivity; i.e., low manpower operation requirements.

There is no known excessive noise or vibration source in the equipment recommended for use with the SLS. The shelter should include adequate sound absorption material to provide a satisfactory working environment; and, finally, the air conditioning system should be vented to minimize offensive odors.

Filling and Loading Methods

The SLS compression/loading chamber can be filled by using a large container in which material may be weighed when hoisted and emptied into the compression/loading chamber. The refuse and soil cover can be placed in cell layers separated by a screen mesh to approximate relative settling of different layers after a test has been completed. During tests, when pressures up to an equivalent of 200-feet landfill depth are simulated, pressure must be kept constant as soil and refuse compaction occurs. The loading device consisting of an inflatable air bag (compactor) mentioned earlier and described in more detail below, placed at the top of the soil tank, can be pressurized to the desired level and maintained at this level as compaction takes place. If landfill bulk density is assumed to be 1,200 lb/yd^3, the pressure required to simulate a 200-foot landfill depth is 62 lb/in^2; i.e., pressure = density x landfill depth,

$$P = 1,200 \frac{lb}{yd^3} \times \frac{1\ yd^3}{27\ ft^3} \times \frac{1\ ft^2}{144\ in^2} \times 200\ ft$$

$$P = 62\ lb/in^2$$

where P = pressure

Depths less than 200 feet can be simulated by pressures below 62 psi; i.e.,

$$P = \rho h$$

where ρ = landfill density

h = depth

The compactor consists of an internal rubber bag for air containment and a heavy external fabric covering for strength and protection. Its internal pressure, simulating landfill depth, is adjusted and controlled by means of a differential pressure regulator, referenced to the internal gas pressure of the test chamber (soil tank). A series of latitudinal rigid hoops are fastened to the bag exterior to allow axial expansion only. As internal air pressure in the bag increases and compaction occurs, the bag expands axially but not radially (see Figure 5), thereby avoiding jamming against the soil-tank walls.

The strength requirement of the air bag inner liner material is estimated below. Considering the bag to be a thin-walled cylindrical pressure vessel, membrane stresses are found by the following equations [16]:

$$S_h = \frac{PR}{t}$$

where, S_h = hoop stress

P = internal pressure

R = radius

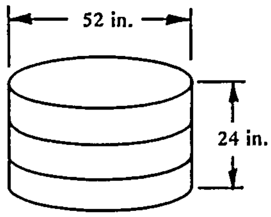
t = thickness

Therefore,

$$S_h = \frac{PR}{t} = \frac{62\ \text{lb/in.}^2 \times 30\ \text{in.}}{t} = \frac{1,860}{t}\ \text{lb/in.}$$

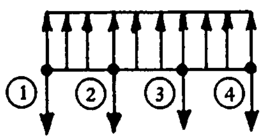
If a factor of safety of about 1.5 is adopted, the material must have a strength on the order of 3,000/t (lb/in.).

The amount of force transmitted to the hoops depends on the relative elasticity of the hoop and bag materials. A very rigid hoop material combined with a comparatively elastic bag material will result in most of the pressure stresses being transmitted to the hoops. If hoops are assumed to take the entire pressure stress, the force per hoop can be approximated by calculating the total hoop force and dividing among the hoops. For example, assume the bag is 24 inches high, 52 inches in diameter, and has four equally spaced hoops.



Total hoop force = 24 in. x 52 in. x 62 lb/in^2

$$P = 77{,}380 \text{ lb}$$



It is reasonable to assume that the two inside hoops take twice as much force as the outside pair so it follows that,

$$2F + 2(F/2) = 77{,}380 \text{ lb}$$

where F is the force on the inside hoops.

Solving for F,

$$F = 25{,}800 \text{ lb}$$

Hence, if all the hoops are strong enough to withstand 25,800-pound tensile stress, the hoops will be structurally sound, regardless of bag material.

Settlement Measurements

Whenever the SLS decomposition/loading chamber is open, the number of rings covered by refuse and soil can be counted and an approximate volume calculated. The corresponding weight of material is known, since the refuse is weighed before it is loaded into the decomposition chamber. Knowing weight and volume, bulk density can be found any time before the tank top is in place. Once the initial conditions are known, an estimate of bulk density is made using settlement data taken during the test.

Settlement measurements are taken using displacement gages [17] placed at critical points in the SLS loading chamber. The essential elements of these gages (available from Bison Instruments, Inc., Minneapolis, Minnesota) are: (1) an instrument package containing driving amplification, balancing, calibration, and readout controls and (2) a pair of disk-shaped sensors imbedded in the soil in near coaxial and parallel orientation, divided by an area over which displacement is to be averaged. The principle of operation entails the mutually inductive coupling between two coaxial sensors within the soil. The electromagnetic coupling is extremely sensitive to axial spacing, hence a direct relationship to displacement can be derived. Displacements of less than 0.1% and larger than 100% can be measured in an operational range of 1 to 40 times the nominal coil diameter.

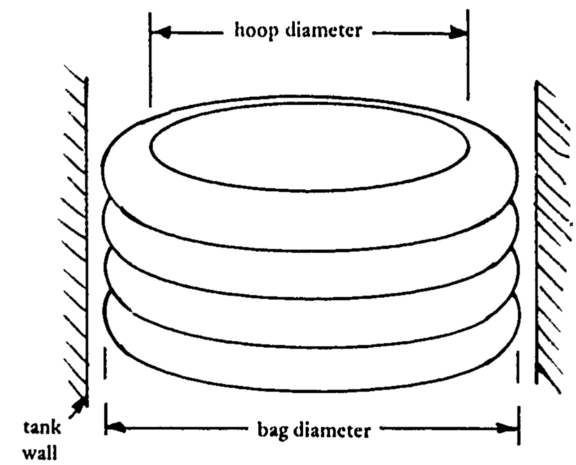
While the coils can easily be aligned in axial and parallel modes at the beginning of the test, some misalignment and rotation during compaction will occur. Lateral misalignment should not be critical, because a lateral shift produces a signal which is an order of magnitude less than the equivalent axial movement. Rotation from parallel is more critical, but if deviation is below ± 20 degrees, the error in measurement will be less than 10%.

Mechanically restraining the coils to restrict lateral translation and rotation is not recommended, as the mechanical coupling can significantly affect the results. The instrument is sensitive to ferrous objects and cannot be located nearer than 2 coil diameters to such materials, including other pairs of coils in the same area. Recommended placement of these gages is shown in Figure 6. They are placed wholly within the measurement zone determined by scaling studies, since this zone provides the most reliable settlement measurements. Redundancy is provided in an effort to minimize errors due to both lateral shift and rotation from horizontal.

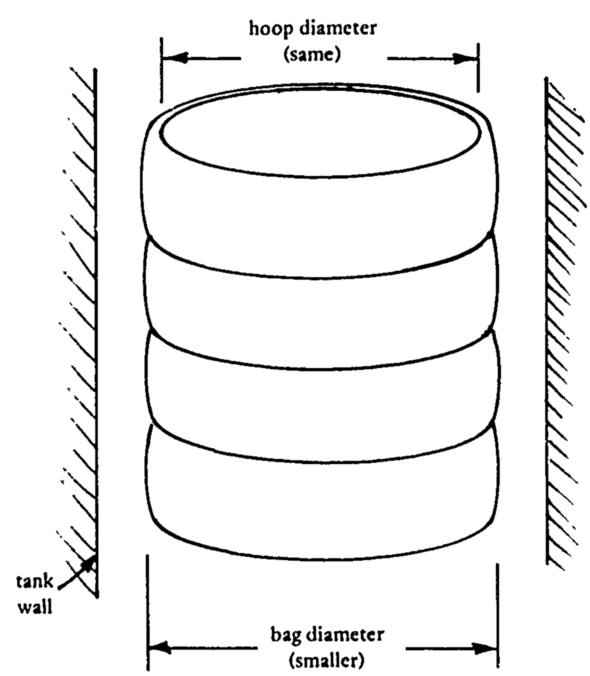
Insulation and Temperature Control

For biological decomposition and physical testing the chamber requires sufficient thermal control to maintain internal temperatures. In addition, temperature should be monitored at enough locations to assure that SLS temperatures and heat flux are representative of actual landfill conditions and that adequate heating and cooling equipment are provided to facilitate operation under ambient temperatures of 30° to 100°F. For pyrolitic decomposition, there are additional requirements that are discussed in a subsequent section on the high temperature design concept.

For low temperature conditions it is assumed that SLS temperature and heat flux will be representative of actual landfill conditions. This would preclude the use of insulation because of the lack of control (of the heat flux) required to simulate location of the measurement zone in the landfill center or at an extremity. If the zone is located at the center, the outside temperature of the insulators should equate to the surrounding earth and surface temperatures of the landfill, and the conductivity should be equal to the landfill material conductivity between the core and the landfill extremity.



(a) Deflated (contracted)



(b) Inflated (extended)

Figure 5. Inflatable air bag.

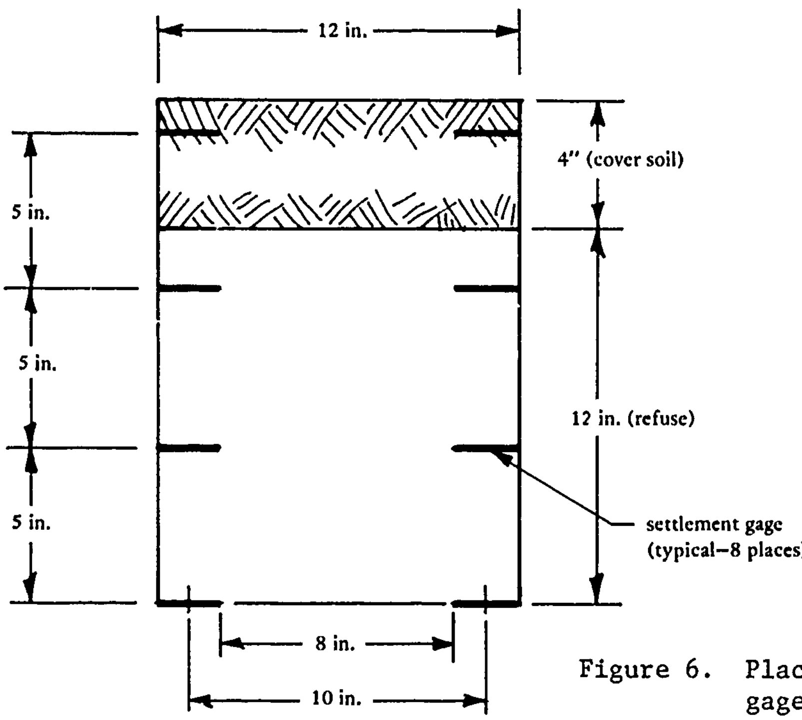


Figure 6. Placement of settlement gages within the measurement zone.

It is therefore recommended that no simulator insulation be used. The simulator should be housed in an insulated structure, which is air-conditioned to a temperature slightly more or slightly less than that of the simulator core. The air would be an excellent buffer, and the solid waste heat flux can then be controlled. It also is recommended that a large door be included in the structure adequate for a forklift and that the structure be large enough to include room for a gantry plus all the auxiliary equipment and instrumentation.

Gases and Sealing

In order to have control over the gaseous atmosphere in the soil tank, it must be sealed from unwanted leakage through tank walls and fittings. The soil tank planned for use presently has some holes in it from previous tests; the openings must be filled and sealed. SLS instrumentation wires, air hoses, and internal piping will be formed into one utility line and coupled with a gas-tight seal between the tank and the outside atmosphere.

The soil-tank rings can be sealed using a viscous, hard-setting sealant, such as Permatex No. 1. According to manufacturer's specifications, this sealant is used in temperatures ranging from -65° to 500°F and for hydrostatic pressures to 5,000 psi. To maintain a seal throughout the test, a compressive stress must be maintained on the rings and their seals. But as a surcharge is applied and internal gas pressure increased, a reaction force will tend to elongate the soil tank structure and relieve the compressive stress on the rings. Precompression may be applied to the rings before the test begins to counteract the elongation force caused by the surcharge and internal gas pressure. The required precompression can be determined by finding the total axial force trying to expand the structure and then adding on a minimum compressive stress for sealing. The surcharge is simulated by a pressurized air bag whose internal pressure is controlled by a differential pressure regulator referenced to the soil tank internal gas pressure. Hence,

$$P_{Total} = P_1 + P_2$$

where P_1 = surcharge pressure on soil

P_2 = internal gas pressure

Maximum surcharge pressure derived from the 200-foot material depth simulation requirement is

$$(P_1)_{max} = 62 \text{ psig}$$

and $(P_2)_{max}$ is arbitrarily estimated at 25 psig.

Therefore,

$$(P_T)_{max} = (P_1) + (P_2) = 62 + 25 = 87 \text{ psig}$$

$$\text{Area of tank top} = \frac{\pi D^2}{4} = \frac{(3.141)(5)^2}{4} \text{ ft}^2 \times \frac{144 \text{ in.}^2}{\text{ft}^2} = 2.830 \text{ in.}^2$$

$$\text{producing pressure force} = P \times A = 87 \frac{\text{lb}}{\text{in.}^2} \times 2,827 \text{ in.}^2 = 246,000 \text{ lb}$$

To assure a good seal, a 500-psi seating stress must be included,

$$F = P \times A = 500 \text{ lb/in}^2 \times \pi Dt$$

$$= 35,300 \text{ lb}$$

where

t = ring thickness

= 3/8 in.

D = 60 in.

Therefore,

$$\text{total precompression force} = 246{,}000 \text{ lb} + 35{,}000 \text{ lb}$$

i.e.,

$$F_{total} = 281{,}000 \text{ lb}$$

Tank Structure Loads and Stresses

There are eight tie rods on the tank, so each tie rod will carry a preload equal to

$$\frac{\text{total precompression force}}{\text{number of rods}} = \frac{281 \text{ kips}}{8 \text{ rods}} = \frac{35 \text{ kips}}{\text{rod}}$$

To ensure that each tie rod carries the proper load, the bolt torques must be applied using a known torque-tension relationship. From Reference 18

$$T = 0.2\ DL$$

where

T = torque

D = bolt diameter

L = bolt load

therefore,

$$\begin{aligned} T &= 0.2\ (2 \text{ in.})(34{,}000 \text{ lb}) \\ &= 13{,}600 \text{ in-lb} = 1{,}130 \text{ ft-lb} \end{aligned}$$

It should be noted that the bolts must be periodically re-torqued, due to stress relaxation in the materials.

Maximum shear stress in the tie rods caused by the applied torque is [18]:

$$\tau_{max} = \frac{2T}{\pi r^3}$$

where τ_{max} = maximum shear stress

T = applied torque

r = rod radius

and

$$\tau_{max} = \frac{2(13,600\ \text{in.-lb})}{(3.141)(\text{in})^3} = 8,660\ \text{psi}$$

Tie rod material is AISI 4140 steel, heat-treated to 105 ksi yield point. The allowable shear stress is

$$\tau_{yield} = \frac{\text{tensile yield strength}}{2} = \frac{105,000\ \text{psi}}{2} = 52,500\ \text{psi}$$

Maximum tensile stress in each tie rod (2-8 UNC bolts) is for a uniform load distribution:

$$P = \frac{F}{A}$$

where

F = maximum tensile force in rod (35,000 pound)

A = effective area of rod (2.77 in.^{2})

so, $P = \dfrac{34,000\ \text{lb}}{2.77\ \text{in.}^2} = 12,600\ \text{psi}$

This is well below the tensile yield point of 105,000 psi. Since the total tensile force caused by the surcharge (246,000 pound) is less than the total tie-rod preload (272,300 pound), the surcharge will not contribute to tie-rod loading.

The maximum compressive stress in the tank rings is

$$P = \frac{F}{A} = 281,000\ \text{lb}/\pi Dt$$

where,

D = Tank diameter (60 inches)

t = Tank ring width (3/8 in.)

and,

$$P = \frac{281,000\ \text{lb}}{(60)(0.375)\ \text{in.}^2} = 12,500\ \text{psi}$$

Three failure modes exist:

1. Euler buckling which is not critical in short columns such as the soil tank rings.

2. Compressive stress in the rings, which will be identical to the gasket stress previously calculated as 3,850 psi, is also well before the yield point.

3. Local buckling constraint of the tank rings, which can be found using the following equation from Reference 19,

$$\sigma_L = K_C \frac{Et}{D}$$

where, σ_L = local buckling stress limit

K_C = 0.4 buckling coefficient

E = modulus of elasticity

t = thickness of rings (3/8 in.)

D = ring diameter

and, $\sigma_L = (0.4)(30 \times 10^6)(3/8) \dfrac{\text{lb/in.}^2 \times \text{in.}}{60 \text{ in.}}$

$\sigma_L \approx 75{,}000 \text{ lb/in}^2$

Hence, a compressive stress of 75,000 lb/in^2 is required for local buckling to occur, which is also well above the working stress.

Gas Control and Instrumentation

Aerobic decomposition conditions will be simulated by introducing ambient air into the chamber through a variable pressure regulator with a small compressor as the regulator's air source.

Anaerobic conditions in the SLS can be created by forcing nitrogen into the chamber at one end, while exhausting the other gases at the opposite end. The nitrogen can be added from a pressurized bottle with a pressure regulator set at no more than 25 psi. Gases will be exhausted through an adjustable back-pressure regulator, allowing a constant internal gas pressure. A number of companies manufacture appropriate pressure reducers for the SLS application. Mass flow rate of inlet and exhaust gases can be measured using a linear mass flow rate of the type manufactured by Airco Industrial Gases. These flow meters will measure mass flow rate without corrections for temperature and pressure of the gas, and a conversion chart also available from Airco will allow a direct reading of either nitrogen flow or air flow. Output of the flow meter is coupled to an integrator chart recorder to allow operators to observe both instantaneous mass flow rate and total mass flow.

The gas enters at the bottom of the SLS chamber through a simple manifold, as shown in Figure 7. This manifold is imbedded in gravel to allow uniform distribution of gas and minimum flow resistance. A liquid trap is installed outside of the tank in the gas line to prevent leachate from entering the instruments and also to provide a convenient place to bleed off any moisture which might collect in the line. A schematic of the gas-injection system is shown in Figure 8.

A gas collection system will be positioned near the tank top with a manifold similar to the distribution manifold shown in Figure 7. By use of a variable pressure relief valve, gas can be collected at any pressure up to 25 psig. This allows the internal pressure of the tank to be controlled while permitting injected or generated gas to vent through the mass flow meter and into a sample container. The sample container can be removed and taken to a laboratory for composition tests. This gas collection system shown in Figure 9, coupled with the inlet system, gives the operator ability to measure and control internal pressure, gas composition, and flow rate through the simulator.

Liquid Control and Instrumentation

Liquid is injected into the SLS through an injection manifold (such as that shown in Figure 10), located in gravel near the top of the decomposition/loading chamber and just below the inflatable air bag loading device. This arrangement is shown in Figure 11. Injection rate can be controlled using an adjustable metering pump such as the C-1500P series produced by Blue White Industries. These pumps have a dial-type flow rate adjustment and pump very low flow rates (0-3 gph). Volumetric flow rates of liquids into the SLS is measured with an Astroflow Liquid Flowmeter, manufactured by AstroDynamics, Inc. This flow meter is accurate for extremely low flow rates and operates at extremely low pressure drops across the instrument. The electrical output is a digital pulse or analog and can be coupled to an integrator to give total volumetric flow.

Liquids which percolate through the soil and refuse layers will be drained by a pipe installed in the soil-tank bottom. The pipe incorporates a graduated transparent section with an ordinary gate valve on the discharge side, as shown in Figure 12. Volumetric flow rate is measured by draining leachate down to a set point on the graduated transparent pipe, by closing the gate valve, and thereby timing the leachate collection. This method allows the operator to observe both flow rate and total volumetric flow without opening the chamber to the atmosphere. A flow meter is not recommended for three reasons: (1) instantaneous flow rates will vary so greatly that valid readings would be improbable, (2) leachate draining out of the tank will surely have many solid particles that a sensitive low flow meter would not tolerate, and (3) difficulty in operating a flow meter without venting some internal gases to the atmosphere in the process would limit the credibility of gas flow measurements.

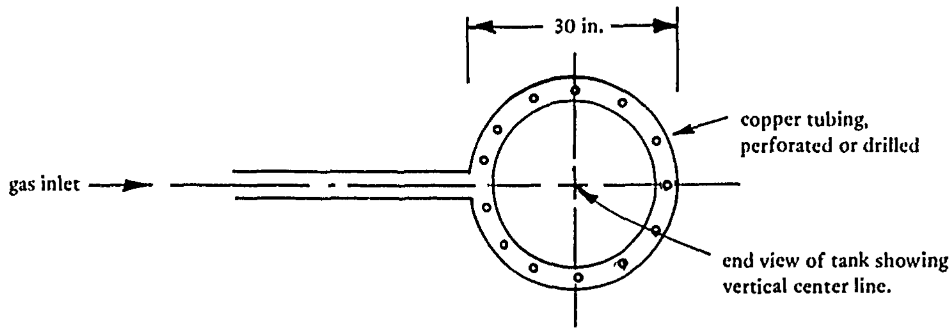


Figure 7. Gas injection manifold.

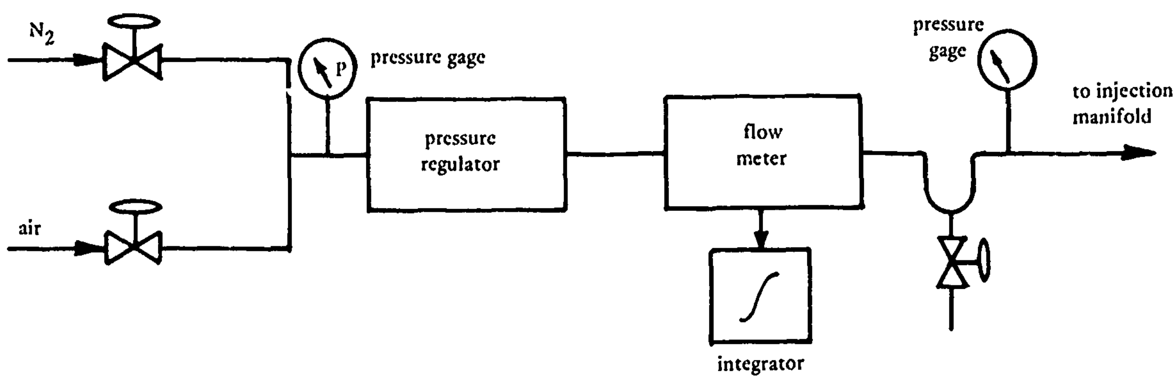


Figure 8. Injection gas control.

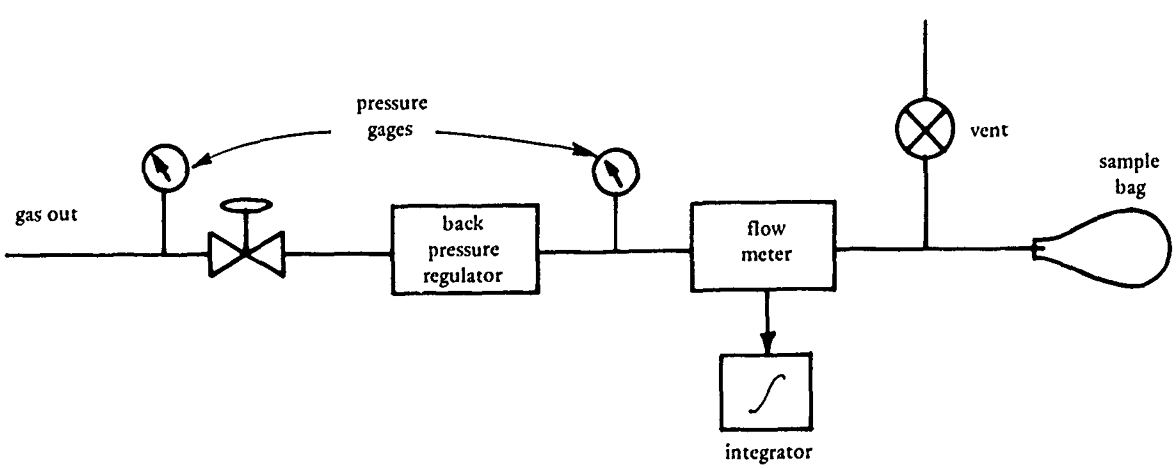


Figure 9. Exhaust gas control.

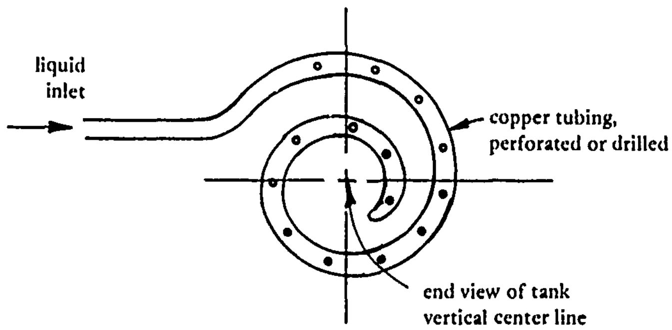


Figure 10. Liquid injection manifold.

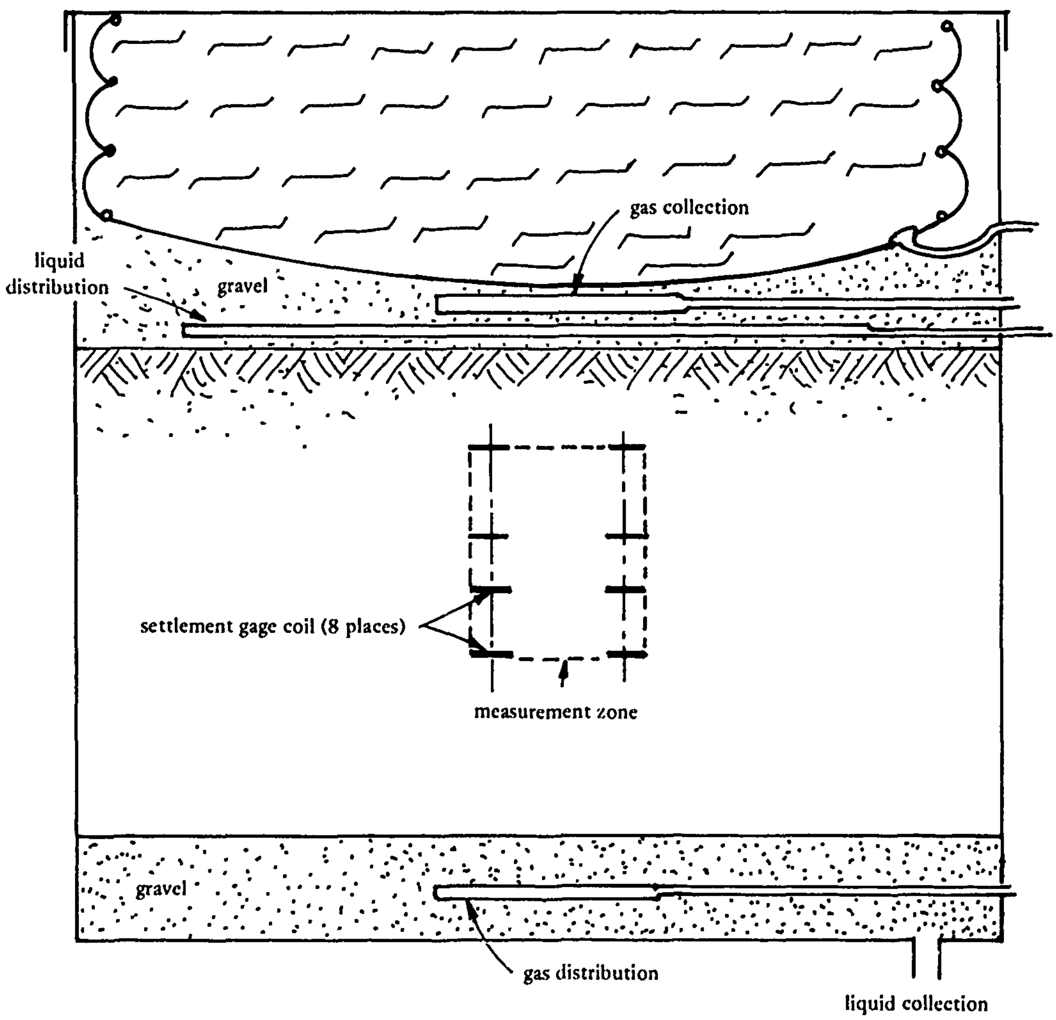


Figure 11. SLS decomposition/loading chamber.

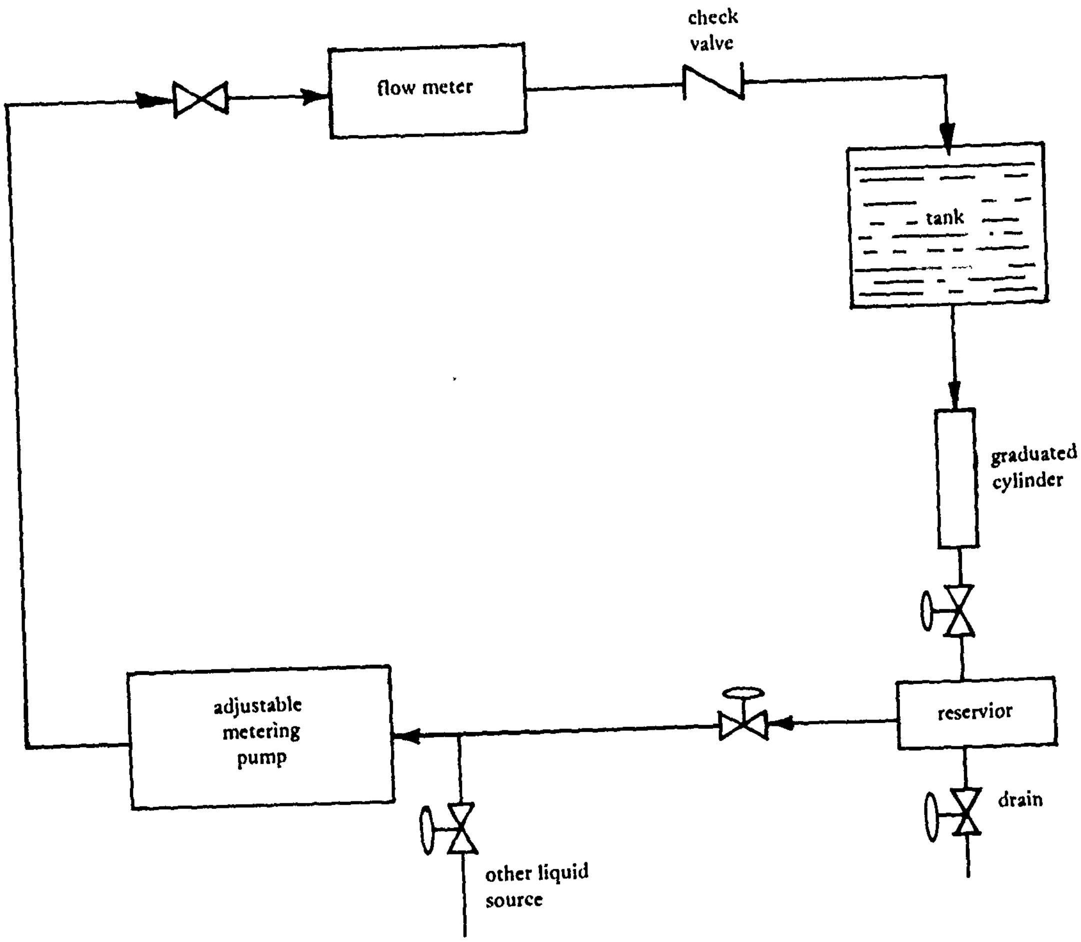


Figure 12. Liquid injection and control.

The leachate drained from the tank is routed to a reservoir where it can be recirculated or drained for sampling. Because the operating temperature of the SLS can approach the atmospheric boiling point of water and, similarly, the internal liquid, to avoid cavitation the liquid pump should not be placed in a position where a suction lift is required.

Permeability Testing

Permeability of material in the SLS chamber will be measurable both vertically and horizontally, without disassembling the chamber, by monitoring the flow and pressure drop of gas or liquid through a defined sample (core).

Permeability of solid waste depends greatly on material composition, particle size, compaction, and temperature. Large and small openings throughout the material will significantly affect permeability. Since solid waste is not homogeneous, the sample core size could greatly affect the accuracy of permeability measurement.

The concept of permeability examined here consists of viscous flow only, as represented by seepage, corresponding to low pressure gradients. The degree of permeability, expressed by the coefficient of permeability, is not discussed. Only the techniques of acquiring a core sample acceptable for permeability testing without disassembling the chamber will be discussed.

If a steady-state measurement which may be very difficult to obtain is desired, both inlet and exit flow rates should be monitored and compared. For steady-state conditions, they must be equal. If time constants plus transport-time delays are excessive, then frequency response tests can be conducted at low frequency sinusoidal input in order to develop confidence in a direct-current gain coefficient. The transport lag (pure time delay) does not affect the attenuation, only the phase.

Instrumentation needed to monitor pressure and flow of the liquid is outlined in the sections on gases and liquids.

Components of the coring tool and the tank ring modifications required for sampling horizontal sections in the test chamber for permeability tests are detailed in Figures 13 and 14. Ideally, this method pushes a 3-inch tube completely through a ring diameter by impacting a 3-inch tube with a manual pile driver. An experiment on a small sample was tried with successful results. The small sample of compacted paper, cloth rags, plastic bags, wood, and food wastes (oranges, bread, and cooking grease) was cored with an available 2-inch tube. Figure 15 illustrates a sample of the cored material. The sharpened end of the corer was bent slightly on the third test when it penetrated into the plywood base. Figure 16 shows the corer embedded in the waste. It is important to note that the cored material was not condensed significantly by the friction of the corer wall.

Permeability in the vertical direction can be measured by monitoring the liquid flow and pressure drop through the entire test chamber itself. Because of inaccuracies derived from core sample size, it is suggested that a vertical core be taken with the 3-inch corer after the solid waste chamber tests are completed and compared to the 5-foot-diameter core tests.

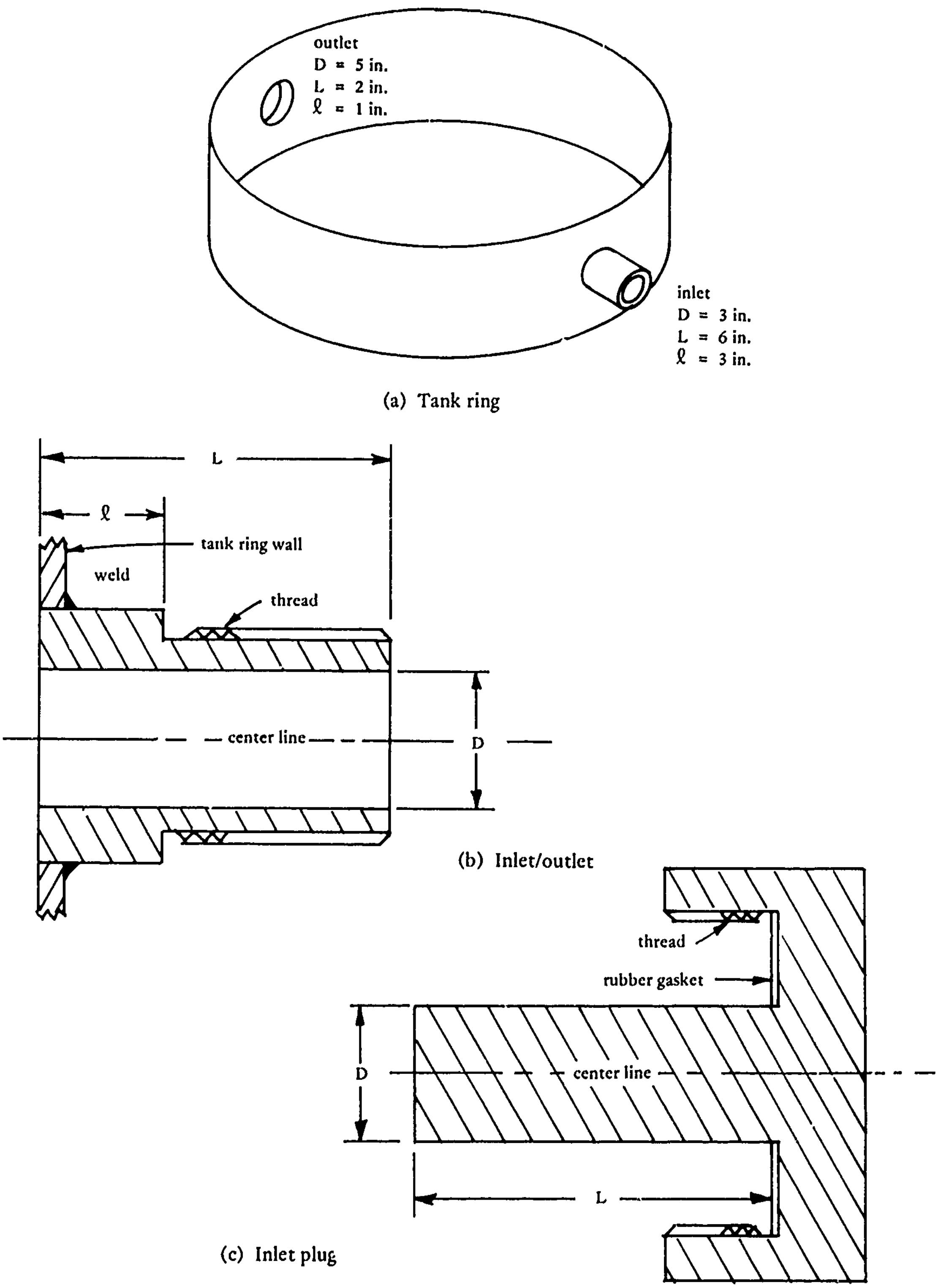


Figure 13. Tank ring modifications for coring.

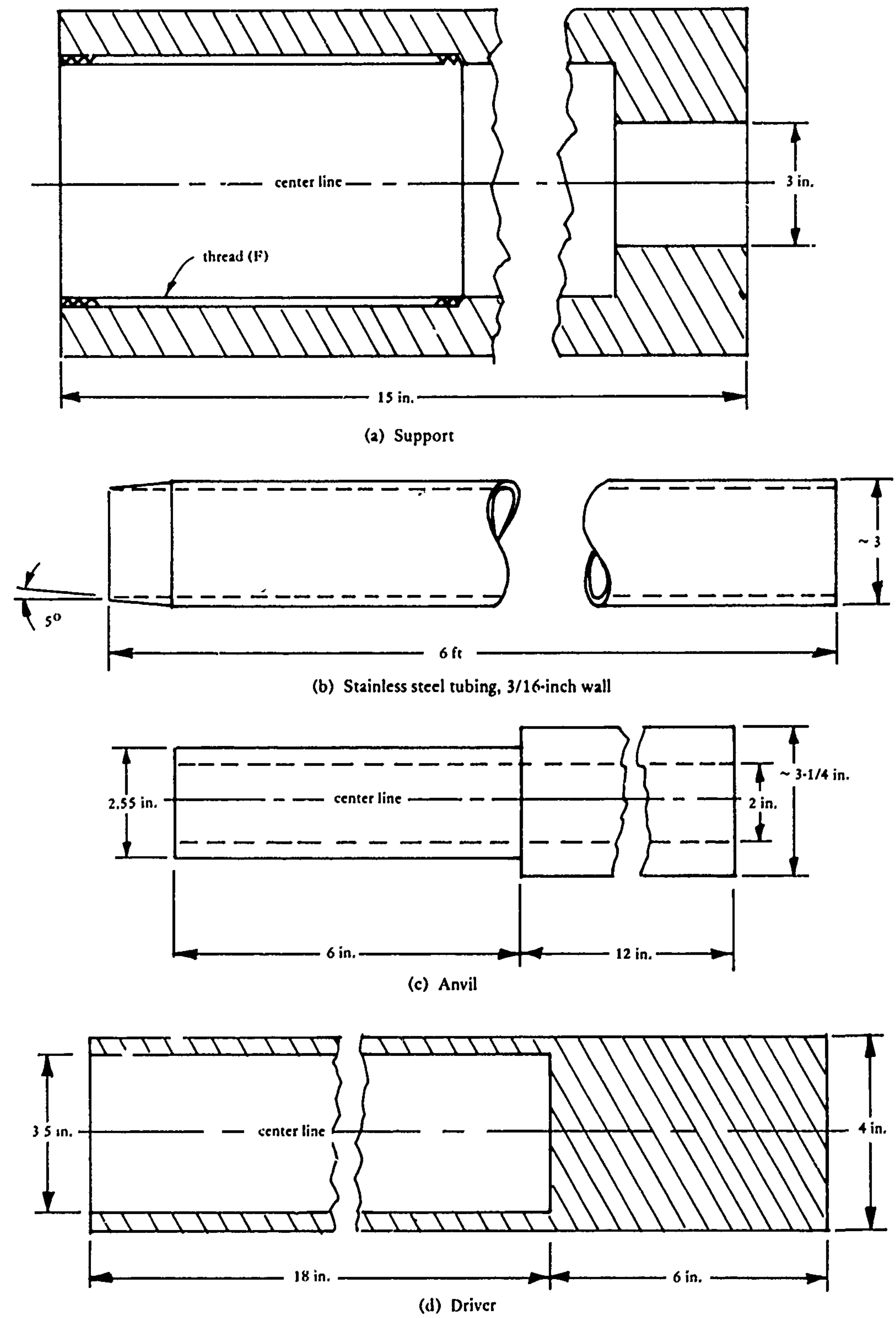


Figure 14. Corer components.

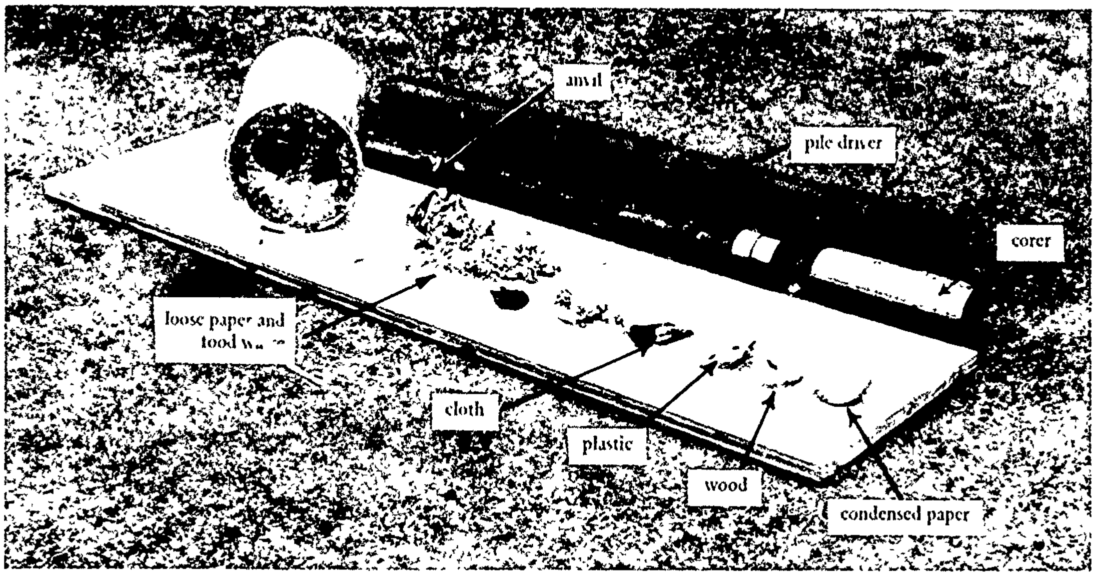


Figure 15. Experimental corer test equipment.

Figure 16. Experimental corer embedded in solid waste.

Operation and Maintenance

Overall system requirements for the SLS decomposition/loading chamber are that: (1) it operate with minimum vibration and noise; (2) all materials and equipment in contact with solid wastes or products of solid waste decomposition (leachate and gases) be resistant to corrosion by these agents; (3) all exposed materials and equipment be adequately protected against an outdoor, ocean front environment; (4) low operating manpower; and (5) minimum odor methods of filling and emptying the SLS of solid waste be provided.

High Temperature Design Concept

In the event that pyrolysis is employed as a means for accelerating refuse decomposition, the SLS high temperature requirement is that the decomposition/loading chamber be designed to withstand an interior temperature of the solid waste and cover soil as high as 1,500°F.

It is believed that a chamber having the same working properties as described for the low temperature SLS (previously described for 200°F refuse temperature) can be designed to withstand an interior temperature of 1,500°F. A satisfactory method for heating the solid waste and cover soil to 1,500°F may, however, be difficult to develop. Design recommendations for high temperature operation are listed below.

1. Insulation and Temperature Control. It is assumed that during the high temperature cycle, the heat flux is not representative of actual landfill conditions. Insulation placed directly next to the decomposition/loading chamber is recommended to minimize the power required to heat the solid waste. The specific insulation type, conductivity, shape, etc., will depend on the heating method.

2. Seal Analysis. A woven asbestos-fiber over gasket capable of sealing gas pressures over 100 psi and resistant to hot water, mild acids, and alkalis is available commercially (Chesterton style 315). Special tank rings are required to fit the high-temperature gasket. The soil tank's top and bottom would also have to be redesigned to meet the seal and temperature requirements.

3. Density and Settlement Measurements. An array of ultrasonic emitters/receivers located so as to scan the measurement zone, is the most promising means of instrumentation for settlement measurements. Steel objects of known dimensions could be placed and monitored in the measurement zone. Density measurements can be determined the same way as in the low-temperature SLS.

4. Compression and Loading. High-temperature-resistant fabrics are available for the loading bag and ring support. Use of asbestos insulation and a recirculating coolant could combine to provide design integrity in the high temperature environment.

CONCLUSIONS

1. In their present stage of development, all the methods, instruments, and devices discussed can satisfy the design requirements of a sanitary landfill simulator.

2. Although the primary effort was limited to concept development and analysis of a low temperature SLS (interior chamber temperature below 200°F), it is believed that a chamber having the same working principles as the low temperature SLS can be designed to operate at 1,500°F.

3. For the low temperature requirement, the CEL soil tank with minimal modification was found adequate for use as the SLS decomposition/loading chamber.

4. An inflatable air bag mechanism could simulate the surcharge.

5. Inductive sensors are believed to be the simplest and most economical type to measure refuse settlement in a low temperature SLS.

6. If the simulator is housed in an insulated structure, air-conditioned to a temperature near that of the refuse, the refuse temperature and heat flux should be representative of actual landfill conditions.

7. Instrumentation and control of gas and liquid flow rates, core temperature, and internal tank pressure are readily achievable with available commercial devices.

8. Horizontal permeability is measurable via core sampling without disassembly of the test chamber, using relatively simple, though special, tools. However, it is not known whether or not the resulting data is representative of either the total test chamber or an actual landfill.

9. Vertical permeability is measurable by simply monitoring flow and pressure drop across the test chamber in the vertical direction.

RECOMMENDATIONS

1. A combined analytical/experimental study of accelerated decomposition techniques is strongly recommended, prior to SLS engineering design, to precisely define the required limits of chamber pressures, temperatures, and gas and liquid flow rates.

2. A feasibility study should be performed to determine if the permeability core size suggested is suitable for acquiring accurate data representative of an actual landfill.

3. An investigation of potential advantage in having a single SLS capable of performing all the tests, rather then several smaller scale simulators specially designed for specific tests, is recommended.

4. Additional analysis of the containing hoops and fabric webbing of the inflatable air bag should be performed to ensure adequate bag life, especially if high temperatures and special insulation techniques are involved.

5. More detailed study of the use of ultrasonics and X-ray for measurement of refuse settlement in a high temperature SLS is recommended, if high temperatures are required.

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